Optical Design and Fabrication

OSA Optics & Photonics Congress

Freeform Optics (Freeform)

Optical Fabrication and Testing (OF&T)

10 June — 12 June 2019

OSA Headquarters

Washington, DC USA

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OSA is pleased to offer complimentary wireless internet services throughout the meeting space at OSA for all attendees and exhibitors.
Network SSID: 2010MassGuest
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Registration

Lobby

Monday, 10 June	06:30—17:00
Tuesday, 11 June	07:00—17:00
Wednesday, 12 June	07:00—17:00

Hosted Lunches, and Networking Coffee Breaks

Lobby

Monday, 10 June	10:00 – 10:30	Exhibits Open and Networking Coffee Break
	12:30 – 14:00	Hosted Lunch
	16:00 – 16:30	Networking Coffee Break
	18:30 – 20:00	Welcome Reception
Tuesday, 11 June	10:00 – 10:30	Networking Coffee Break
	12:30 – 14:00	Hosted Lunch
	16:00 – 16:30; 16:30 – 18:00	Networking Coffee Break and Joint Manufacturing Session
	18:00 – 19:30	Joint Poster Session and Networking Coffee Break
Wednesday, 12 June	10:00 – 10:30	Networking Coffee Break
	12:30 – 14:00	Hosted Lunch
	16:00 – 16:30	Networking Coffee Break

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OSA Anti-harassment Policy and Code of Conduct

OSA is committed to providing an environment that is conducive to the free and robust exchange of scientific ideas. This environment requires that all participants be treated with equal consideration and respect. While OSA encourages vigorous debate of ideas, personal attacks create an environment in which people feel threatened or intimidated. This is not productive and does not advance the cause of science. All participants in OSA and OSA-managed events and activities are therefore expected to conduct themselves professionally and respectfully.

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- contact any OSA staff member (if onsite at an event or meeting)
- use the online portal osa.org/IncidentReport (or email CodeOfConduct@OSA.org)

Plenary Speakers

Plenary Session

Monday, 10 June, 08:00—10:00
P St Combined

Amy Newbury
DigitalGlobe, Inc., *USA*

08:30—09:15

Building A Better World: A Real World Application of Optical Technology
Through DigitalGlobe's maps and analytics, satellite imagery is used for an extensive set of applications. This paper shows how at Maxar Technologies, we use precision optics to fulfill our mission to "Build a Better World."

Amy Newbury is a Director and Aerospace Fellow at DigitalGlobe, a Maxar Technologies company. She graduated with a PhD in Physics from Princeton University after which she was a National Research Council Post-Doctoral fellow at the National Institutes of Standards and Technology. Since then, she has worked in the aerospace field, first at MIT Lincoln Laboratory, then as a Staff Consultant at Ball Aerospace. She has been at DigitalGlobe for the past 8 years. While at Ball Aerospace, she served as Lead Engineer for several programs including a NOAA sounder instrument study and for the LANDSAT Operational Land Imager instrument. At DigitalGlobe, she worked extensively on the suite of imagers on the Worldview-3 satellite. She is currently the Chief Instrument Engineer for the Legion constellation slated to launch in the 2021 timeframe, and continues to explore future satellite missions aligned with Maxar's purpose to "Build a better world".

Pablo Benítez
Universidad Politecnica de Madrid, *Spain*

09:15—10:00

Folded Freeform Optics for Virtual Reality
Future virtual reality will require optics enabling much slimmer headsets, such as folded (catadioptric) architectures that will be reviewed here, from the classical pancake lens to the latest freeform multichannel Thineyes® solutions proposed by Limbak.

Pablo Benitez is professor at the Technical University of Madrid, Spain, where he leads the Optical Engineering group. In the last 20 years he has pioneered research in design of aspheric and freeform optics for nonimaging and imaging applications, specifically he is co-inventor of the SMS optical design method. More recently, Pablo Benitez has cofounded and is CTO of Limbak, which is an IP company developing advanced freeform optics for the forthcoming VR and AR glasses.

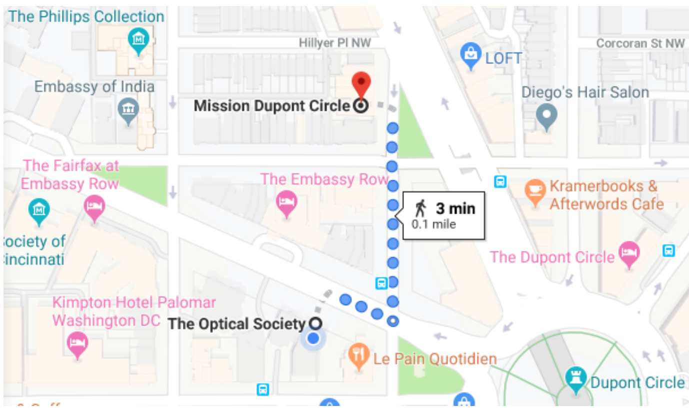
Special Events and Awards

Joint Plenary Session
Monday, 10 June, 8:00 — 10:00
P St Combined

The Optical Design and Fabrication Congress will feature two Plenary speakers. For more information on the Plenary speakers, see the descriptions on the previous page.

Welcome Reception
Monday, 10 June, 18:30 — 20:00
Mission (1606 20th St NW, Washington, DC 20009)

Join your fellow attendees for a fiesta at Mission—only steps away from OSA! Enjoy the summer air, delectable fare, and cerveza or margarita in this hacienda-style venue while networking. The event is open to committee/presenting author/student and full conference attendees. Conference attendees may purchase extra tickets for their guest for $75.



Moving Across Fields: From Academia to Industry and Back Again
Tuesday, 11 June, 12:30 — 13:30
Lower Lobby

Navigating the change from academia to industry or from industry to academia is not always a straightforward path. Alexis Vogt, PhD, Chair and Associate Professor of Optics at Monroe Community College, will share her experiences moving between the two fields.

Hosted by: OSA CareerLab

The Future of Additive Manufacturing Technologies for Optical Applications
Tuesday, 11 June, 16:30 — 18:00
P St Combined

What role will additive manufacturing play in optical system design, material choices, and optical component fabrication? Come join a panel of additive manufacturing technology leaders for an interactive discussion about what additive manufacturing can do for the optics community, industry, and academia.

Panelists
Rebecca Dylla-Spears, *Lawrence Livermore National Laboratory,* USA
Joseph Howard, *NASA Goddard,* USA
Matthew Jenkins, *Raytheon,* USA
Michael Sweeney, *General Dynamics,* USA
Daniel Werdehausen, *Carl Zeiss AG,* Germany

Joint Poster Session
Tuesday, 11 June, 18:00 — 19:30
Perkin and Small Conference Rooms

This Congress will feature a joint poster session including nearly 30 poster presentations. Posters are an integral part of the technical program and offer a unique networking opportunity where presenters can discuss their results one-to-one with interested parties.

Poster Set-Up and Removal
All posters must be set during lunch. The presenter must remain in the vicinity of their poster for the duration of the session. All presenters must remove their posters at the conclusion of the session. Any posters left will be discarded.

Kevin P. Thompson Optical Design Innovator Award 2019 Recipient

Kyle Fuerschbach, Sandia National Laboratories, USA

For ground breaking work utilizing nodal aberration theory to design, manufacture, and test a fully functional first-ever free form imaging telescope in a fully rotationally nonsymmetric configuration, demonstrating revolutionary freeform surfaces in optical imaging systems.

The Kevin P. Thompson Optical Design Innovator Award recognizes significant contributions to lens design, optical engineering, or metrology by an individual as evidenced by one or more of the following: innovative and rigorous research; optical system design with a foundation in aberration theory; development of advanced metrology capabilities; product development; patents; or publications.

The award was established in 2017 in memory of Kevin P. Thompson, who, among many other accomplishments, was known for leading breakthroughs in the understanding of the aberration fields of a new class of truly nonsymmetric optical systems using freeform optical surfaces. It is endowed by several supporters including Jannick Rolland and Synopsys.

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Explanation of Session Codes

FM2B.4

Meeting Name

F= Freeform
O = OF&T
J = Joint

Number

(presentation order within session)

Day of the Week Designation

M=Monday
T=Tuesday
W= Wednesday

Series Number

1 = First Series of the Session
2 = Second Series of the Session

Session Designation

(alphabetically)

The first letter of the code designates the meeting. The second element denotes the day of the week . The third element indicates the session series in that day (for instance, 1 would denote the first sessions in that day). Each day begins with the letter A in the fourth element and continues alphabetically through the parallel session. The lettering then restarts with each new series. The number on the end of the code (separated from the session code with a period) signals the position of the talk within the session (first, second, third, etc.). For example, a presentation coded FM2B.4 indicates that this paper is being presented as part of the Freeform meeting on Monday (M) in the second series of sessions (2), and is the second parallel session (B) in that series and the fourth paper (4) presented in that session.

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Agenda of Sessions

Monday, 10 June		
	P St A	P St B
	OF&T	Freeform
06:30—17:00	Registration, *Lobby*	
08:00—10:00	JM1A • Opening Remarks and Joint Plenary Session, *P St*	
10:00—10:30	Networking Coffee Break, *Perkin and Small Conference Rooms*	
10:30—12:30	OM2A • Optical Standards and Fabrication Tolerances	FM2B • Freeform Imaging Design I (ends at 12:15)
12:30—14:00	Hosted Lunch	
14:00—16:00	OM3A • Large Optics Manufacturing and Testing	FM3B • Freeform Imaging Design II
16:00—16:30	Networking Coffee Break , *Perkin and Small Conference Rooms*	
16:30—18:30	OM4A • Optical Surface Finishing and Testing	FM4B • Freeform in Space Applications
18:30—20:00	Congress Reception, *Mission (1606 20th St NW, Washington, DC 20009)*	

Tuesday, 11 June		
	P St A	P St B
	OF&T	Freeform
07:00—17:00	Registration, *Lobby*	
08:00—10:00	OT1A • Modern Fabrication and Surface Characterization Techniques	FT1B • Freeform Illumination I
10:00—10:30	Networking Coffee Break , *Perkin and Small Conference Rooms*	
10:30—12:30	OT2A • Novel Optical Materials and Components	FT2B • Freeform Illumination II
12:30—14:00	Hosted Lunch	
12:30—13:30	Moving Across Fields: From Academia to Industry and Back Again, *Lower Lobby*	
14:00—16:00	OT3A • Additive Manufacturing	FT3B • Postdeadline Session (begins at 15:15)
16:00—16:30	Networking Coffee Break , *Perkin and Small Conference Rooms*	
16:30—18:00	JT4A • Joint Manufacturing Session: The Future of Additive Manufacturing Technologies for Optical Applications, *P St*	
18:00—19:30	JTu5A • Joint Poster Session, *Perkin and Small Conference Rooms*	

Agenda of Sessions

Wednesday, 12 June		
	P St A	P St B
	OF&T	Freeform
07:00—17:00	**Registration,** *Lobby*	
08:00—10:00	**JW1A • Freeform Optics Manufacturing I***, P St*	
10:00—10:30	**Networking Coffee Break ,** *Perkin and Small Conference Rooms*	
10:30—12:30	**JW2A • Freeform Optics Metrology and Testing***, P St*	
12:30—14:00	**Hosted Lunch**	
14:00—16:00	**JW3A • Freeform Optics Manufacturing II***, P St*	
16:00—16:30	**Networking Coffee Break ,** *Perkin and Small Conference Rooms*	
16:30—18:30	**OW4A • Optical Metrology and Testing**	**FW4B • Freeform Systems** (ends at 18:15)

06:30—17:00 • Registration, *Lobby*

JM1A • Joint Plenary Session, *P St Combined*

08:00 -- 10:00
JM1A • Plenary Session
Presider: Jessica DeGroote Nelson, Optimax Systems Inc, USA

JM1A.1 • 08:00 Plenary
Building A Better World: A Real World Application of Optical Technology, Amy Newbury[1]; *[1]DigitalGlobe, Inc., USA.* Through DigitalGlobe's maps and analytics, satellite imagery is used for an extensive set of applications. This paper shows how at Maxar Technologies, we use precision optics to fulfill our mission to "Build a Better World."

JM1A.2 • 08:45 Plenary
Folded Freeform Optics for Virtual Reality, Pablo Benítez[1]; *[1]Universidad Politecnica de Madrid, Spain.* Future virtual reality will require optics enabling much slimmer headsets, such as folded (catadioptric) architectures that will be reviewed here, from the classical pancake lens to the latest freeform multichannel Thineyes® solutions proposed by Limbak.

10:00—10:30 • Networking Coffee Break, *Perkin and Small Conference Rooms*

Monday, 10 June

P St A

OF&T

10:30 -- 12:30
OM2A • Optical Standards and Fabrication Tolerances
Presider: Chris Evans; Univ of North Carolina at Charlotte, USA

OM2A.1 • 10:30 Invited
Design for Manufacturing: Tolerancing and Optimization, Brian J. Bauman[1], Michael D. Schneider[1]; [1]*Lawrence Livermore National Laboratory, USA.* We present recent work that produces optical designs that have increased robustness to misalignments. In other words, we optimize a design for maximum as-built performance, not for maximum nominal performance. We also discuss future extensions.

OM2A.2 • 11:00
Modeling Interferometric Measurement Error of Small Radius Parts with a Phase-Shifting Fizeau using the Y-Y Bar Diagram, Reem Alsalamah[1]; [1]*Univ. of Alabama in Huntsville, USA.* The y-y bar diagram presents the geometrical analysis of the focusing wave with a small radius. It is Introducing the Phase shift in Fizeau the impact of the three cases of the small spherical test surface.

OM2A.3 • 11:15 Invited
Realistic Optical Drawing Specifications from a Metrology Point of View, Bruce E. Truax[1]; [1]*Ametek Zygo, USA.* This talk will look at the moresomewidely used optical surface specifications and provide guidance on how to use them properly to minimize the ambiguity between the customer and the supplier.

OM2A.4 • 11:30
Testing and Characterization of Challenging Optics and Optical Systems with Shack Hartmann Wavefront Sensors, Remy Juvenal[1], Guillaume Dovillaire[1], Philippe Clemenceau[1]; [1]*Imagine Optic, USA.* In this talk, we present the capabilities of metrology systems based on Shack-Hartman wavefront sensing for aberration measurements of challenging optics such as optical filters, thin flat optics, aspheric lenses and large optical assemblies.

OM2A.4 • 11:45
High Precision Optical Metrology Challenges in a Real-world Smart Glasses Manufacturing Environment, Cynthia N. Nelson[1], Ian Andrews[1], Vance Morrison[1], Brian Cranton[1], Rajiv Iyer[1], Pisek Kultavewuti[1], Geoff White[1], Victor Isbrucker[1]; [1]*North Inc., Canada.* North's smartglasses integrate everyday eyewear with a discrete display. Many of the optical components in the display are unique, requiring innovative metrology for validation. This paper describes our optical metrology challenges and solutions.

OM2A.5 • 12:00 Invited
Modern Optics Drawings: Understanding the Nuances of ISO 10110 Drawings, Eric Herman[1], Dave Aikens[2], Richard N. Youngworth[3]; [1]*Zygo Corporation, USA;* [2]*Savvy Optics Corp., USA;* [3]*Riyo LLC, USA.* The optics industry continues to operate globally with accessibility to designers and fabricators across the world. Communicating optical requirements in a standardized way is needed. This paper addresses working with the ISO 10110 drawing standard.

P St B

Freeform

10:30 -- 12:15
FM2B • Freeform Imaging Design I
Presider: John Rogers; Synopsys, Inc, USA

FM2B.1 • 10:30 Invited
Freeform Optics for AR: From Free-space Combiners to Waveguide Grating Combiners, Bernard Kress[1]; [1]*Microsoft Corp., USA.* Abstract not available.

FM2B.2 • 11:00
Surface Construction of Freeform Imaging Systems by Numerical Integration, Jean-Baptiste Volatier[1], Guillaume Druart[1]; [1]*ONERA, France.* We present a method where an ordinary differential equation problem is derived from the Fermat path's principle and is integrated to construct freeform surfaces. We discuss preliminary results of the method, its limitations and future work.

FM2B.3 • 11:15
Freeform Optical Surfaces for Field Biased and Decentered Aperture Reflective Optical Design, Kyle Fuerschbach[1]; [1]*Sandia National Laboratories, USA.* A decentered Zernike overlay is utilized in the design of a field biased off-axis wide field of view reflective imager and the optical performance with this surface type is compared to a conic only solution.

FM2B.4 • 11:30
All-Reflective Freeform Viewfinder, Aaron M. Bauer[1], Matthias Pesch[2], Julius A. Muschaweck[3], Jannick P. Rolland[1]; [1]*Univ. of Rochester, USA;* [2]*Arnold & Richter Cine Technik GmbH & Co. Betriebs KG, Germany;* [3]*JMO GmbH, Germany.* An all-reflective electronic viewfinder was designed using tilted freeform surfaces in a fully unobscured package. Tight distortion and telecentricity requirements moved the design from a two-mirror solution to a five-mirror solution.

FM2B.5 • 11:45
Nonsymmetric Imaging Optics Design Combining Freeform Surfaces and Flat Phase Elements, Tong Yang[1], Dewen Cheng[1], Yongtian Wang[1,2]; [1]*Beijing Inst. of Technology, China;* [2]*AICFVE of Beijing Film Academy, China.* We proposed the point-by-point design method of imaging optics consisting of freeform surfaces and flat phase elements. This kind of system has the advantages of good-performance, more compactness, lighter-weight and easier-alignment.

FM2B.6 • 12:00
A Design Method of Linear-Astigmatism-Free Three-Mirror Freeform Imaging Systems, Seunghyuk Chang[1]; [1]*Center for Integrated Smart Sensors, Korea (the Republic of).* A design method of three-mirror freeform imaging system is presented. The freeform design is obtained by optimizing mirror surfaces starting from a linear-astigmatism-free confocal conic mirror system.

OM2B.7 • 12:15
Using the Instrument Transfer Function to Evaluate Fizeau Interferometer Performance, Leslie L. Deck[1], Peter J. de Groot[1]; [1]*Zygo Corporation, USA.* Advances in test procedures and analysis techniques now enable reliable instrument transfer function measurements to 1000 cycles per aperture independent of several traditional sources of uncertainty and operator error.

12:30—14:00 • *Hosted Lunch*

P St A	P St B
OF&T	Freeform

14:00 -- 16:00
OM3A • Large Optics Manufacturing and Testing
Presider: Dae Wook Kim; Univ. of Arizona, USA

OM3A.1 • 14:00 Invited
Optical Finishing and Lightweighting of Large Mirrors, Tony Hull[1], Thomas Westerhoff[2]; *[1]Univ. of New Mexico, USA; [2]SCHOTT AG, Germany.* Methods of large mirror optical finishing and substrate lightweighting are ideally linked to yield minimum schedule and optimal performance. Environments experienced in both service and processing impose constraints on optimal materials and processes.

OM3A.2 • 14:30
Suppressing Surface Low and Mid-Spatial Frequency Errors of Large Optics During Full-aperture Rapid Polishing, Ruiqing Xie[1,2], Shijie Zhao[2], Defeng Liao[2], Xianhua Chen[2], Jian Wang[2], Qiao Xu[2], Xinxing Ban[1], Huiying Zhao[1], Zhuangde Jiang[1]; *[1]State Key Laboratory for Manufacturing Systems Engineering, Xi'an Jiaotong Univ., China; [2]Research Center of Laser Fusion, China Academy of Engineering Physics, China.* A full-aperture rapid polishing process (RPP) for efficiently manufacturing of large optics is introduced. The low and mid-spatial frequency errors were suppressed by deterministically conditioning polishing pad and optimizing process parameters.

OM3A.3 • 14:45 Invited
Manufacturing ELT Optics: Year 2 Report, Remi Bourgois[1], Roland Geyl[1]; *[1]SAFRAN REOSC, France.* We will present the status of our activities related to the ELT M1 to M4 optical fabrication and testing.

OM3A.4 • 15:15
Alignment and Testing of Large Lenses using Computer Generated Holograms, James H. Burge[1,2], Art Mihill[1], Wes Pullen[1], Zach Walker[1], Chunyu Zhao[2], Marty Valente[1]; *[1]Arizona Optical Systems, USA; [2]Arizona Optical Metrology, USA.* CGH Interferometry provides the standard for accurate measurement of transmitted wavefront for large lenses. With multiple patterns on the same substrate, a CGH also enables simultaneous measurements of multiple degrees of freedom used for alignment.

OM3A.5 • 15:30 Invited
Interferometric Metrology for the TMT Primary Mirror Segments: Design and Analysis, Jake Beverage[1], James H. Burge[1,2], Jon Blanchard[1], Ben Lewis[1], Chunyu Zhao[2], Marty Valente[1]; *[1]Arizona Optical Systems, USA; [2]Arizona Optical Metrology, USA.* The Thirty Meter Telescope uses a hyperboloidal *f*/1 primary mirror made from 492 1.4-m segments with 82 different aspheric prescriptions. Each segment will be measured using Fizeau interferometry with spherical reference and CGH aspheric correction.

14:00 -- 16:00
FM3B • Freeform Imaging Design II
Presider: Harvey Spencer; DRS Technologies, Inc, USA

FM3B.1 • 14:00 Invited
Construction-iteration Method for the Design of Freeform Reflection System, Benqi Zhang[1], Guofan Jin[1], Jun Zhu[1]; *[1]Tsinghua Univ., China.* Construction-iteration (CI) methodology is developed for the design of various types of reflection optical systems containing freeform surfaces, which is recently applied in automatic design of imaging systems and the design of dispersive systems.

FM3B.2 • 14:30
The Effect of Freeform Surfaces on the Volume and Performance of Unobscured Three-Mirror Imagers, Eric M. Schiesser[1], Aaron M. Bauer[1], Jannick P. Rolland[1]; *[1]Univ. of Rochester , USA.* The volume reduction capabilities of freeform surfaces compared to off-axis aspheres is presented in the context of unobscured three-mirror imagers. A design study demonstrates the effectiveness of freeform mirrors, reducing the volume by up to 25%.

FM3B.3 • 14:45
A Sag Equation for Both On-Axis and Off-Axis Conics, Suitable for use as a Base Surface for Freeform Optics, Nicholas Takaki[1], Jonathan Papa[1], Jannick P. Rolland[1]; *[1]Univ. of Rochester, USA.* A formula for calculating conic section sag is presented, both for on-axis and off-axis conics. Existing conic section sag equations are examined, including potential numerical instabilities. Design applications are explored.

FM3B.4 • 15:00
Use of Freeform Surfaces to Break Misalignment Signature Degeneracies of a Three-Mirror Telescope, Alessandra Croce[1], Erin Elliott[1]; *[1]Zemax LLC, USA.* Alignment of multi-mirror optical systems can be a challenging task. This paper demonstrates how freeform surfaces may be used to create non-degenerate alignment signals in a three-mirror telescope.

FM3B.5 • 15:15
Automated Design of Unobscured Four-mirror Freeform Imaging Systems, Yunfeng Nie[1], Fabian Duerr[1], Heidi Ottevaere[1]; *[1]Department of Applied Physics and Photonics, Vrije Universiteit Brussel, Belgium.* We present design tools that enables an automated generation of starting geometries for freeform mirror systems, including automatically removing obscuration and direct calculation of all surfaces coefficients while minimizing related aberrations.

FM3B.6 • 15:30 Invited
Applications of Freeform Optics in Near-eye Displays, Dewen Cheng[1]; *[1]Beijing Inst. of Technology, China.* Abstract not available.

16:00—16:30 • Networking Coffee Break , *Perkin and Small Conference Rooms*

P St A	P St B
OF&T	Freeform

16:30 -- 18:30
OM4A • Optical Surface Finishing and Testing
Presider: Chunyu Zhao; Arizona Optical Metrology LLC, USA

OM4A.1 • 16:30 Invited
Introduction of Chemical Mechanical Planarization (CMP) for Semiconductor Device Manufacturing, Sidney Huey[1]; *[1]Applied Materials Inc., USA.* This presentation introduces CMP and several novel techniques to control material removal during polishing. These real-time *insitu* control techniques may be of interest to the optics community. CMP originated from optics polishing.

OM4A.2 • 17:00
Observations on the Effect of Retrace Error in Scanning White Light Interferometry of Smooth Optical Surfaces, Clark Hovis[1], Hossein Shahinian[2], Chris J. Evans[1]; *[1]Center for Precision Metrology, Univ. of North Carolina at Charlotte, USA; [2]Micro-LAM Inc., USA.* Retrace errors in interferometric measurements is a known phenomenon. The impact of retrace error in stitching CSI measurements is studied, estimates of retrace error in a CSI instrument and methods in correcting it is outlined.

OM4A.3 • 17:15
Spectrally Controlled Interferometry for Improved Radius of Curvature Measurement, Chase Salsbury[1], Artur G. Olszak[1]; *[1]Apre Instruments, USA.* Spectrally controlled interferometry offers advantages for radius of curvature measurements by removing the catseye position during measurement and exploiting the inherent ability to measure absolute distance without mechanical compensation.

OM4A.4 • 17:30
Holographic Fabrication of Graded Photonic Super-crystals using Spatial Light Modulator, Yuankun Lin[1], David Lowell[1], Safaa Hassan[1]; *[1]Univ. of North Texas, USA.* Using the pixel-by-pixel phase engineering in a spatial light modulator together with reflective optical element, we have studied holographic fabrication of graded photonic super-crystals with a square lattice in square and hexagonal symmetries.

OM4A.5 • 17:45
Specification of Optical Surfaces with Anisotropic Mid-spatial Frequency Errors, Hamidreza Aryan[1], Thomas J. Suleski[1]; *[1]Univ of North Carolina at Charlotte, USA.* Mid-spatial frequency (MSF) errors impact optical performance. Conventional surface specification methods assume isotropy, which gives misleading results for surfaces with anisotropic errors. We propose an alternate surface specification method.

OM4A.6 • 18:00 Invited
Advancements in Ion Beam Figuring, Thomas Arnold[1,2], Jens Bauer[1], Fred Pietag[1]; *[1]Leibniz Institut of Surface Modification, Germany; [2]Technische Universität Dresden, Germany.* The paper addresses recent advancements of Ion beam figuring (IBF) aiming at the increase of precision for correction of midspatial wavelengths. New developments for increasing productivity and improving machinability of metal surfaces are presented.

16:30 -- 18:30
FM4B • Freeform in Space Applications
Presider: Joseph Howard; NASA Goddard Space Flight Center, USA

FM4B.1 • 16:30 Invited
Automatic Solution Space Exploration for Freeform Optical Design, Jonathan C. Papa[1], Joseph M. Howard[2], Jannick P. Rolland[1]; *[1]Univ. of Rochester, USA; [2]NASA Goddard Space Flight Center, USA.* First, second, and third-order aberration theory are applied to reduce the degrees of freedom to generate starting designs for freeform imagers. This provides the framework to perform a complete search of the solution space.

FM4B.2 • 17:00
CHIMA: Design and Performances of a Freeform Grating High Spectral Resolution Spectro-Imager, Benoit Borguet[1], Vincent Moreau[1], Alessandro Zuccaro Marchi[2], Micael Miranda[2], Arnaud Cotel[3]; *[1]R&D, AMOS, Belgium; [2]ESA-ESTEC, Netherlands; [3]Horiba Europe Research Center, France.* We present the design and tested performances of the Compact Hyperspectral Imager for Monitoring of the Atmosphere (CHIMA): a high spectral resolution (0.6 nm/pixel) spectro imager featuring freeform grating, curved slit and keystone corrector.

FM4B.3 • 17:15
CubeSat Format 3-Mirror Spectrometer Designed with Freeform Surfaces, Yuxuan Liu[1], Aaron M. Bauer[1], Jannick P. Rolland[1]; *[1]The Inst. of Optics, Univ. of Rochester, USA.* A design study about a 3-mirror freeform spectrometer that fits in a 1U CubeSat format. Performances are compared between the freeform and off-axis asphere designs.

FM4B.4 • 17:30
Ultralight Very Large Aperture Space Telescopes using MODE Lens Technology, Youngsik Kim[1], Zichan Wang[1], Tom Milster[1]; *[1]Univ of Arizona, Coll of Opt Sciences, USA.* New ultralight space-telescopes using multiple-order-diffraction-engineered (MODE) lenses can be ultralightweight, transmissive, and very large aperture. Diffraction-limited, 0.24-m nine-segment MODE-lens telescope is designed for astronomical R-band.

FM4B.5 • 17:45
Precision Freeform Optics for Space Science Missions: MicroCarb - IASI NG - MERLIN, Roland Geyl[1]; *[1]SAFRAN REOSC, France.* Safran Reosc is contributing to the two key science missions MicroCarb and IASI NG with precision freeform optics. We will report about instrument design and optical fabrication.

FM4B.6 • 18:00 Invited
Freeform Surface Characterization and Instrument Alignment for Freeform Space Applications, Manal A. Khreishi[1], Raymond Ohl[1], Joseph M. Howard[1], Jonathan C. Papa[1], Clark Hovis[1], Andrew Howe[2], Theodore Hadjimichael[1], Patrick Thompson[1], Ron Shiri[1], Garrett West[1], Adam Phenis[3], Rongguang Liang[4]; *[1]NASA, USA; [2]Norfolk State Univ., USA; [3]AMP Optics, LLC, USA; [4]The Univ. of Arizona, USA.* CMM metrology provides simple, 3D surface data used for prescription retrieval, figure error, and alignment with high accuracy without null-correctors. Two freeform mirrors for a compact telescope were successfully characterized and aligned using the CMM.

18:30—20:00 • Congress Welcome Reception, *Mission (1606 20th St NW, Washington, DC 20009)*

07:00—17:00 • Registration, *Lobby*

Tuesday, 11 June

P St A

OF&T

08:00 -- 10:00
OT1A • Modern Fabrication and Surface Characterization Techniques
Presider: John Tamkin; Imaging Insights LLC, USA

OT1A.1 • 08:00
PSD on the Shop Floor: Controlling MSF Errors and Keeping CCP Machines Honest, Brandon Dube[1]; [1]*Aperture Optical Sciences, USA.* Computer-Controlled Finishing Technologies produce a new family of MSF errors. PSD highlights them and guides process choices for their control. We show an example of this for a high energy laser focusing mirror.

OT1A.2 • 08:15
Non-Directional Modulation Transfer Function for Optical Surfaces with Anisotropic Mid-Spatial Frequency Errors, Hamidreza Aryan[1], Thomas J. Suleski[1]; [1]*Univ of North Carolina at Charlotte, USA.* Sub-aperture manufacturing creates anisotropic surface errors, and modulation transfer functions (MTF) not well represented by 1D cross-sections. We present a 1D 'non-directional' MTF for specification and characterization of optical surface errors.

OT1A.3 • 08:30
Predictive Models for Grinding & Polishing of Various Optical Materials, Tayyab I. Suratwala[1]; [1]*Lawrence Livermore National Laboratory, USA.* The following study presents useful quantitative rules, based on fundamental mechanisms, for the determining the grinding & polishing rate and grinding roughness during optical fabrication for a variety of optical workpiece materials.

OT1A.4 • 08:45
Germanium Polishing via Femtosecond Laser Radiation, Lauren Taylor[1], Jing Xu[2], Thomas Smith[3], Michael Pomerantz[2], John Lambropoulos[2], Jie Qiao[1]; [1]*Rochester Inst. of Technology, USA;* [2]*Univ. of Rochester, USA;* [3]*Aperture Optical Sciences, USA.* Femtosecond laser polishing of germanium was demonstrated by controlling laser parameters to realize smooth processing. Scalable material removal with optical quality was achieved, showing the capability of femtosecond lasers for precision polishing.

OT1A.5 • 09:00
Micro Laser Assisted Machining (Micro-LAM) of Precision Optics, Hossein Shahinian[1], Dmytro Zaytsev[1], Jayesh Navare[1], Yang Su[1], Di Kang[1], Deepak Ravindra[1]; [1]*Micro-LAM, USA.* This paper summarizes the application of the µ-LAM process to the fabrication of precision brittle optical components. Predictive optical modeling, and examples of enhancements to conventional diamond machining by the µ-LAM system are introduced.

OT1A.6 • 09:15
A Technique to Control Global Figure using Acid Immersion and Zernike Decomposition, Andrew Nelson[1]; [1]*Zygo Corporation, USA.* Introduction of a technique to control the global figure of an optical substrate that leverages the bulk removal efficiency of a full aperture process but has the determinism of a sub-aperture figuring approach.

OT1A.7 • 09:30 Invited
R2R-UV-nanoimprinting as a Powerful Mean for Large-area Fabrication of Freeform Microoptical Elements*,* Barbara Stadlober[1], Claude Leiner[1], Dieter Nees[1], Anja Haase[1], Ursula Palfinger[1], Ladislav Kuna[1], Stephan Ruttloff[1], Martin Smolka[1], Jan Hesse[1], Max Sonnleitner[2], Christian Sommer[1]; [1]*Joanneum Research, Austria;* [2]*Genspeed Biotech GmbH, Austria.* We demonstrate the fabrication of low-cost freeform micro-optical elements for lighting, display, medical diagnostics via the related process chain combining optical design, direct laser lithography, step&repeat imprinting and R2R nanoimprinting.

P St B

Freeform

08:00 -- 10:00
FT1B • Freeform Illumination I
Presider: Rengmao Wu; Zhejiang Univ., China

FT1B.1 • 08:00 Invited
Interplay of Freeform Tailoring and Tolerancing, William J. Cassarly[1]; [1]*Synopsys, Inc, USA.* The design and fabrication of freeform optics for illumination has matured dramatically over the last few decades. For many cases, tolerancing the design has become the critical step in the design process. We present examples to illustrate.

FT1B.2 • 08:30
Freeform Lens Design for a Point Source and Far-field Target, Lotte B. Romijn[1], Jan ten Thije Boonkkamp[1], Wilbert IJzerman[1,2]; [1]*Eindhoven Univ. of Technology, Netherlands;* [2]*Signify Research, Netherlands.* A method is presented for the design of a freeform lens for a point source and far-field target. We use a least-squares algorithm to solve the generalized Monge-Ampère equation for a few test problems.

FT1B.3 • 08:45
Prescribed Illuminance Design for Extended Lambertian Sources in Two-dimensional Geometry with Aspherical Lenses, Zhanghao Ding[1], Lin Yang[1], Jinlei Zhang[1], Peng Sun[1], Yuan Chen[1], Rengmao Wu[1], Zhenrong Zheng[1]; [1]*State Key Laboratory of Modern Optical Instrumentation, College of Optical Science and Engineering, Zhejiang Univ., China.* We develop a method for designing aspherical lenses in two-dimensional geometry, which can be used to redirect the light rays from extended Lambertian sources to produce a prescribed illuminance distribution with a short lighting distance.

FT1B.4 • 09:00
Data-Driven Freeform Irradiance Tailoring, Matthew Brand[1], Daniel A. Birch[1]; [1]*Mitsubishi Electric Research Labs, USA.* We develop data-driven high-étendue freeform irradiance tailoring for design problems where the incident light is known only through a sampling of its rays, and the transport from freeform to projection is nontrivial.

FT1B.5 • 09:15
Segmented Freeform Reflector for Confocal Raman/SERS Detection, Qing Liu[1], Hugo Thienpont[1], Heidi Ottevaere[1]; [1]*Vrije Universiteit Brussel, Belgium.* We present the design and fabrication of a segmented freeform reflector for confocal Raman and SERS spectroscopic analysis in a microfluidic-based system. Further, we simulate the confocal performance and assess the results by experiments.

FT1B.6 • 09:30 Invited
Freeform Optics for Illumination and Supporting Quadric Method (SQM), Vladimir Oliker[1]; [1]*Emory Univ., USA.* Redistribution of light to create prescribed intensity patterns on given sets in 3D is a task arising in beam shaping, illumination of curved surfaces, and many others. The Supporting Quadric Method was developed to solve these design problems.

10:00—10:30 • Networking Coffee Break, *Perkin and Small Conference Rooms*

P St A — OF&T

10:30 -- 12:30
OT2A • Novel Optical Materials and Components
Presider: Thomas Arnold; Leibniz Institut of Surface Modification, Germany

OT2A.1 • 10:30 Invited
Cordierite Design, Manufacturing and Performance, Shinobu Nagata[1], Yasuhiro Nakahori[2], Shinji Mukai[2], Jimmy Estrada[1], Andrew Shobe[1], Masa Kamiura[2], Yasu Ikeda[1]; *[1]Kyocera International, Inc., USA; [2]Kyocera Corporation, Japan.* Next generation telescope mirrors require materials with low thermal expansion, high stiffness, long-term dimensional stability, and ease of manufacturability. CO720 cordierite is superior in these aspects when compared to competing glass materials.

OT2A.2 • 11:00
Nanocomposites – A Route to Better and Smaller Optical Elements?, Daniel Werdehausen[1,2], Sven Burger[3,4], Isabelle Staude[2], Thomas Pertsch[2,5], Manuel Decker[1]; *[1]Carl Zeiss AG, Germany; [2]Inst. of Applied Physics, Abbe Center of Photonics, Friedrich Schiller Univ. Jena, Germany; [3]JCMwave GmbH, Germany; [4]Zuse Inst. Berlin, Germany; [5]Fraunhofer Inst. for Applied Optics and Precision Engineering, Germany.* Nanocomposites offer tunable optical properties. We discuss the regime, in which they are suitable for optical systems, show that they unlock a wide range of properties, and investigate their potential for refractive and diffractive devices.

OT2A.3 • 11:15
Glass Printing for Optics using a Filament-fed Laser-heated Process, Edward Kinzel[1], Nicholas Capps[1], Jonathan Goldstien[2], Johnson Jason[3]; *[1]Univ. of Notre Dame, USA; [2]Material and Manufacturing, Air Force Research Laboratory, USA; [3]Mechanical and Aerospace Engineering, Missouri Univ. of Sci. and Tech., USA.* Glass poses unique challenges for additive manufacturing. A Laser-Heated Filament-Fed process has been developed to deposit transparent glass for both refractive free-form optics and free-standing light-guiding structures.

OT2A.4 • 11:30
Hybrid Metasurface-refractive Lenses, Wei-Ting Chen[1], Yousef Ibrahim[1], Alexander Zhu[1], Federico Capasso[1]; *[1]Harvard Univ., USA.* We report dispersion-engineered metasurfaces with wavelength-dependent phase profiles to correct optical aberrations in refractive lenses from a simple singlet spherical lens to a complicated oil-immersion objective.

OT2A.5 • 11:45
Prototyping of Monolithic Diffractive-refractive Micro-optics with Inkjetable Polymers, Jan Klein[1], Johannes Wolf[1], Susanne Gruetzner[1], Margit Ferstl[2], Arne Schleunitz[1], Gabi Gruetzner[1]; *[1]Micro Resist Technology GmbH, Germany; [2]Fraunhofer Heinrich Hertz Inst., Germany.* A novel manufacturing chain to cost-effectively generate prototypes of hybrid micro-optical components is proposed. UV-molding and inkjet printing techniques are combined with optical polymer inks for easily implementing tailor-made optical designs.

OT2A.6 • 12:00 Invited
3d Printed Glass Optics with Tailored Composition, Rebecca Dylla-Spears[1], Du T. Nguyen[1], Nikola Dudukovic[1], Timothy Yee[1], Koroush Sasan[1], Frederick Ryerson[1], Michael A. Johnson[1], Oscar Herrera[1], Lana Wong[1]; *[1]Lawrence Livermore National Laboratory, USA.* Three-dimensional (3d) printing has opened the door to novel glass optics with tailored composition and structure. Glass optics with custom refractive index profiles have been prepared using 3d printing, and optical performance will be discussed.

P St B — Freeform

10:30 -- 12:30
FT2B • Freeform Illumination II
Presider: Fabian Duerr; Vrije Universiteit Brussel, Belgium

FT2B.1 • 10:30 Invited
Illumination Freeform Design using Monge-Ampere Equations, Jan ten Thije Boonkkamp[1], Wilbert IJzerman[2,1]; *[1]Technische Universiteit Eindhoven, Netherlands; [2]Signify Research, Netherlands.* As a generic model for freeform optical systems, we combine the optical map and the luminous flux conservation law into a generalized Monge-Amp\`{e}re equation. We sketch a least-squares solution strategy.

FT2B.2 • 11:00
Precise Light Control in Highly Tilted Geometry by Freeform Illumination Optics, Rengmao Wu[1], Zhanghao Ding[1], Lin Yang[1], Zhenrong Zheng[1]; *[1]Zhejiang Univ., China.* We develop a general formulation for designing freeform illumination optics in highly tilted geometry. Numerical and experimental results show a precise control of light propagation is achieved.

FT2B.3 • 11:15 Invited
Prescribed Intensity Patterns from Extended Emitters by Means of a Generalized Wavefront-tailoring Method, Simone Sorgato[1], Julio Chaves[2], Fabian Duerr[1], Hugo Thienpont[1]; *[1]Vrije Universiteit Brussel, Belgium; [2]Limbak 4Pi, Spain.* We present a method to associate wavefronts to a given intensity pattern. This “wavefront-tailoring” technique is at the core of a powerful wavefront-coupling design tool, particularly suited for freeform illumination optics with extended sources.

FT2B.4 • 11:45
Conformal Mappings for Reflector Construction and Assessment., Luis Aleman-Castaneda[1], Miguel A. Alonso[1,2]; *[1]University of Rochester, USA; [2]Institut Fresnel, Aix-Marseille University, France.* We present an approach to understand the relation between a reflector's shape and the direction in which light gets reflected based on a simple conformal map. Applications for 2D segmented and continuous reflectors are presented.

FT2B.5 • 12:00 Invited
Optimal Transport Theory to Simplify Freeform Design, ZeXin Feng[1], Brittany Froese[3], Rongguang Liang[2], Dewen Cheng[1], Yongtian Wang[1]; *[1]Beijing Inst. of Technology, China; [2]Univ. of Arizona, USA; [3]New Jersey Inst. of Technology, USA.* For zero-étendue sources, optimal transport (OT) theory can simplify the freeform optics design for prescribed irradiance by providing a proper ray map. For coherent light sources, OT theory can obtain an initial estimate.

12:30—14:00 • *Hosted Lunch*

12:30—13:30 • Moving Across Fields: From Academia to Industry and Back Again; *Lower Lobby*

P St A	P St B
OF&T	**Freeform**

14:00 -- 16:00
OT3A • Additive Manufacturing
Presider: Rebecca Dylla-Spears; Lawrence Livermore National Laboratory, USA

OT3A.1 • 14:00 Invited
Design and Build of a Zoom Telescope Utilizing Additive Manufacturing, Edward Winrow[1], Jeffrey Hunt[1], Victor Chavez[1]; [1]*Sandia National Laboratories, USA.* Developers of optical systems are seeking lighter, cheaper, and rapidly-developed systems. Design, fabrication, and testing a 10x dual-focus telescope is presented utilizing additive manufacturing, active alignment, and image correction algorithms.

OT3A.2 • 14:30
Design and Ultraprecision Diamond Machining of Beam Shaping Components for High-power CO2 Lasers in Additive Manufacturing Applications, Jurgen Van Erps[1,2], Gebirie Y. Belay[1,2], Sijie Liao[1,2], Anje Van Vlierberghe[4], Piet Van den Ecker[3], Tom Craeghs[3], Hugo Thienpont[1,2], Michael Vervaeke[1,2]; [1]*Vrije Universiteit Brussel, Belgium;* [2]*Flanders Make, Belgium;* [3]*Materialise, Belgium;* [4]*Flanders Make, Belgium.* We present the design of refractive beam shaping optics for transforming a circular Gaussian beam into a top hat beam for an additive manufacturing process. The designed components are prototyped in zinc sulfide using single-point diamond turning.

OT3A.3 • 14:45
Leveraging 3D Printing to Streamline Precision Optical Manufacturing, Ian Ferralli[1], Matthew Brunelle[1], Thomas Hordin[1]; [1]*Optimax Systems Inc, USA.* Optimax uses a variety of different 3D printers in our manufacturing process that streamline many aspects of the process. Measurement fixtures, machine repair and slurry containment are areas where 3D printing helps streamline manufacturing.

OT3A.4 • 15:00
3D Printed Micro Lenses for Depth of Focus Imaging, Kelli Kiekens[1], David Vega[1], Jude Coompson[1], Hao Xin[1], Jennifer Barton[1]; [1]*Univ. of Arizona, USA.* We rapidly designed, 3D printed, and tested a singlet lens with an outer diameter of 0.5mm and extended depth of focus, for endoscopic applications. Practical considerations and comparison to commercially-available microlenses are provided.

OT3A.5 • 15:15
Task-Specific Computational Refractive Element via Two-photon Additive Manufacturing, Brian J. Redman[1], Amber Dagel[1], Bryan Kaehr[1], Charles LaCasse[1], Gabriel C. Birch[1], Tu-Thach Quach[1], Meghan A. Galiardi[1]; [1]*Sandia National Laboratories, USA.* We report on the design and fabrication of a computational imaging element used within a compressive task-specific imaging system. Fabrication via two-photon 3D printing is reported, as well as characterization of the fabricated element.

OT3A.6 • 15:30 Invited
Additive Manufacturing of Micro-optics: Micro - Meso - Macro, Ruth Houbertz[1], B. Stender[1], W. Mantei[1], Y. Dupuis[1], A. Krupp[1], F. Hibert[1]; [1]*Multiphoton Optics GmbH, Germany.* Industrial High-precision 3D Printing via two-photon absorption (TPA) provides freedom in design for the fabrication of novel products which are not feasible with conventional techniques from the micro to the macro scale.

15:15 -- 16:00
JT3B • Postdeadline Session
Presider: Jannick Rolland; University of Rochester, USA

JT3B.1 • 15:15
Tailored Shearing Interferometry Using Geometric Phase., Luis Aleman-Castaneda[1], Miguel A. Alonso[1,2], Bruno Piccirllo[3], Lorenzo Marrucci[3], Enrico Santamato[3]; [1]*University of Rochester, USA;* [2]*Institut Fresnel, Aix-Marseille Univ., France;* [3]*Department of Physics "E. Pancini", University of Naples Federico II, Italy.* We present a novel mechanism for performing common-path shearing interferometry using geometric phase, enabling almost any directional derivative while securing compactness and robustness. Important applications in freeform optics testing may result.

JT3B.2 • 15:30
A New Family of Freeform Telescope Types, David R. Shafer[1]; [1]*David Shafer Optical Design, USA.* A new type of compact reflective telescope is described which has two or three freeform mirrors and an extra reflection between the mirrors. Very high anastigmatic aberration correction is achieved. Several

JT3B.3 • 15:45
Freeform Aspheric Version of the Offner 1.0X relay, David R. Shafer[1]; [1]*David Shafer Optical Design, USA.* Abstract: A conventional aspheric version of the Offner relay has a much larger rectangular field size than the narrow width annular field of Offner's design. A freeform aspheric design further extends the diffraction-limited field size

16:00—16:30 • Networking Coffee Break, *Perkin and Small Conference Rooms*

16:30—18:00 • Joint Manufacturing Session: The Future of Additive Manufacturing Technologies for Optical Applications, *P St Combined*

What role will additive manufacturing play in optical system design, material choices, and optical component fabrication? Come join a panel of additive manufacturing technology leaders for an interactive discussion about what additive manufacturing can do for the optics community, industry, and academia.

Panelists

Rebecca Dylla-Spears, *Lawrence Livermore National Laboratory,* USA
Joseph Howard, *NASA Goddard,* USA
Matthew Jenkins, *Raytheon,* USA
Michael Sweeney, *General Dynamics,* USA
Daniel Werdehausen, *Carl Zeiss AG,* Germany

18:00—19:30
JT5A • Joint Poster Session, *Perkin and Small Conference Rooms*

JT5A.1 • The Optical Design and Fabrication of a Wide-field 2-mirror Unobscured Freeform Imaging Telescope, Mao Xianglong[1], Yongjun Xie[1], Jinpeng Li[1], Rong Gao[1], Wei Zhao[1]; *[1]Xi'an Inst of Opt and Precision Mech, China.* We describe the design, fabrication, metrology and assembly of an all-aluminium, unobscured, 2-mirror, 20°×15° field of view, F/3.7, visible light, freeform telescope. All-aluminum configuration has the superiority of athermal and cost effective.

JT5A.2 • Fast Design Method of Smooth Freeform Lens with an Arbitrary Aperture for Collimated Beam Shaping, Mao Xianglong[1], Yongjun Xie[1], Jinpeng Li[1], Wei Zhao[1]; *[1]Xi'an Inst of Opt and Precision Mech, China.* A method is proposed for the fast design of a freeform lens for shaping a collimated light beam with an arbitrary contour. Simulation result confirms the effectiveness of the method.

JT5A.3 • Withdrawn

JT5A.4 • Properties of Complex Shaped SiO_2 Glass Lens by New Manufacturing Method, Tomohisa Komiya[1], Kiyoaki Shinohara[1], Takuya Miyazaki[1], Yusuke Chiba[1], Hiroshi Ida[1]; *[1]Nikon, Japan.* Complex shaped lens made of SiO_2 glass was fabricated with a new manufacturing method. The lens and DUV-LED were joined with Au-Sn foil to prevent deterioration by humidity and these properties were measured.

JT5A.5 • Design of a Two-mirror Telescope using A Free-form Surface Whose Conic Constant of the Secondary Mirror is Variable with Respect to the Height of the Incident Ray, Jorge d. Alvarado-Martínez[2], Fermín Granados Agustín[2], Sergio Vazquez Montiel[1], Elizabeth Percino Zacarias[2], Alejandro Cornejo Rodriguez[2]; *[1]Universidad Interserrana del Estado de Puebla-Ahuacatlan, Mexico; [2]Instituto Nacional de Astrófisica, Óptica y Electrónica, Mexico.* We propose the design of a free-form surface for the secondary mirror of a telescope using the different conic values for the secondary allow the surface to be modeled through a polynomial adjustment.

JT5A.6 • Efficient Fabrication and On-machine Measurement of Freeform Aluminum Mirrors by Single Point Diamond Turning Technique, Jingfei Ye[1], Zhenzhen Song[1], Jun Yu[2], Shixin Pei[1], Qun Yuan[3], Zhishan Gao[3]; *[1]Nanjing Univ. of Infor. Sci. and Tech., China; [2]Tongji Univ., China; [3]Nanjing Uni. of Sci. & Tech., China.* Two freeform aluminum mirrors are manufactured efficiently by the SPDT machine. The fabrication parameters and on-machine measurement are analyzed. They form a prototype of an off-axis freeform display optical system with good performance.

JT5A.7 • Early Identification of Patterning Errors in the Fabrication Process of Diffraction Gratings, Sofia Corzo -Garcia[1], Ulf Griesmann[1]; *[1]NIST, USA.* We describe a focal plane imager with high dynamic range for the detection of fabrication errors that occur in the lithographic fabrication of diffraction gratings.

JT5A.8 • Gradient Optics DLL (GODLL) Generator, Simon Tsaoussis[1], Hossein Alisafaee[1]; *[1]Rose Hulman Inst. of Technology, USA.* We have developed a software toolbox for creating an arbitrary, user-defined gradient index profile for use with OpticStudio Zemax. Three examples are also provided to demonstrate the user experience and the procedure.

JT5A.9 • Recycle Loop Deployed for the Large Optical Components of Megajoule Laser, Philippe Cormont[1], Benoit Da Costa Fernandes[1], Carole Houee[1], Mathilde Pfiffer[1], Daniel Taroux[1]; *[1]CEA Cesta, France.* New capabilities including laser micro-shaping and chemical treatment have been developed in an optics recycle loop to bring Megajoule laser (LMJ) damaged large optics (40cmx40cm) back to an operational condition.

JT5A.10 • Onion-ring Bokeh Simulation by Nagata Patch Ray-tracing, Shinya Kaneko[1], Shin-Ya Morita[1], Yutaka Yamagata[2]; *[1]School of Engineering, Tokyo Denki Univ., Japan; [2]RIKEN center for advanced photonics, RIKEN, Japan.* Fabricating error after polishing of the aspheric lens generates onion-ring bokeh of the single lens camera. We simulated them using Nagata patch ray-tracing method.

JT5A.11 • Observations on Ductile Laser Assisted Diamond Turning of Tungsten Carbide, Di Kang[1], Jayesh Navare[1], Yang Su[1], Dmytro Zaytsev[1], Deepak Ravindra[1], Hossein Shahinian[1]; *[1]Micro-LAM, USA.* X-ray diffraction and scanning electron microscopy were used to assess the subsurface integrity of tungsten carbide samples processed by micro laser assisted machining. The effects of laser power and tool condition were evaluated.

JT5A.12 • Detection and Quantification of Surface Defects in Silicon during Diamond Turning , Neha Khatri[1], Suman Tewary[1], Harry Garg[1], Vinod Karar[1], Ravindra K. Sinha[1]; *[1]CSIR-CSIO, India.* In present research ,the optimum machining conditions during diamond turning of silicon to achieve defect free surface are identified &depth of defect encountered during various machining combinations using image processing technique is evaluated.

JT5A.13 • Freeform Surface Measurement with Experimental Ray Tracing – Refraction vs. Reflection, Tobias Binkele[1], David Hilbig[1], Mahmoud Essameldin[1], Thomas Henning[1], Friedrich Fleischmann[1]; *[1]Univ. of Applied Sciences Bremen, Germany.* Experimental Ray Tracing is the equivalent of Ray Tracing in simulations, but in reality. We have developed and compared two experimental measurement setups to measure freeform surfaces, one based on refraction, one based on reflection.

JT5A.14 • Implementing Hartmann Type Null Screens to Test Cemented Doublet Lenses, Maria del Carmen Lopez[1], Maximino Avendaño-Alejo[1], Gabriel Castillo-Santiago[1]; *[1]Instituto de Ciencias Aplicadas y Tecnología, UNAM, Mexico.* A new design of Hartmann type null screens to test qualitatively cemented doublet lenses is presented. The designs of these null screens are based on the knowledge of caustic surface and an exact ray tracing .

JT5A.15 • Measuring Temperature-dependent Refractive Index Coefficient (dn/dT) of the IR Chalcogenide Glass in LWIR using a Twyman-Green Interferometer, Robert Y. Chou[1], Greg R. Schmidt[1], Duncan T. Moore[1]; *[1]Univ. of Rochester, USA.* The dn/dT of the IR Chalcogenide glass is measured in LWIR by using a Twyman-Green Interferometer. The measured sample is a round disk with parallel optically flat surfaces. The results are provided from -53°C ~32°C.

18:00—19:30

JT5A • Joint Poster Session, *Perkin and Small Conference Rooms*

Tuesday, 11 June

JT5A.16 • All-inorganic $Y_3Al_5O_{12}$:Ce^{3+}, Mn^{2+} Phosphor-in-Glass for Warm W-LED, Hang Lin[1], Yuansheng Wang[1]; [1]*Chinese Academy of Sciences, China.* A novel all-inorganic luminescent material, $Y_{2.94}Al_{4.9}O_{12}$: 0.06Ce^{3+}, 0.1Mn^{2+} phosphor-in-glass, has been developed, and the w-LED using it as color converter yields warm white light with desirable color quality as well as excellent thermal stability.

JT5A.17 • Polymer Polishing, Polypropylene and Polytetrafluoroethylene Lenses for a Terahertz Application , Rafael Izazaga-Pérez[1], Valentin López-Cortez[1], Javier Arriaga-Petrona[1], Yesenia García-Jomaso[2], Jose Miguel Arroyo-Hernandez[1], Jose Armando De la Luz-Portilla[1], Magdalena Hernandez-Rios[1]; [1]*INAOE, Mexico;* [2]*ICAT-UNAM, Mexico.* We show the results for the fabrication of polymer lenses by using conventional polishing, the materials selected have low absorption in Terahertz, the lenses will be used in a Near Field Microscopy interferometer.

JT5A.18 • Advanced Confocal Microscopy for Rapid Nanoscale Topography of Surfaces, Ming-Che Chan[1], Chi-Sheng Hsieh[1], Guanyu Zhao[2]; [1]*Inst. of Photonic System, Taiwan;* [2]*Inst. of New Drug Development, China Medical Univ., Taiwan.* An advanced confocal microscope with nanoscale depth resolutions and the capability for rapid capture of 3D surface topography was presented. The proposed microscope shows great promise for optical testing of electronic or photonic elements.

JT5A.19 • Direct Measurement of Phase-related Parameters of Narrow-linewidth Lasers based on 120-degree Phase Difference Interferometer, Xi Zhang[1,2], Fei Yang[1], Zitong Feng[1,2], Jiejun Zhao[1,2], Fang Wei[1], Haiwen Cai[1], Ronghui Qu[1]; [1]*Shanghai Inst of Optics and Fine Mech, China;* [2]*Center of Materials Science and Optoelectronics Engineering, Univ. of Chinese Academy of Sciences, China.* We propose a method to directly measure the phase-related characteristics of narrow-linewidth lasers based on a 120-degree phase difference interferometer. The lasers can be in the state of static or frequency-tuning.

JT5A.20 • Optimizing Contact Area Geometry and Taper Composition in Microknot Resonators, Alexandra Blank[1], Yoav Linzon[1]; [1]*Tel Aviv Univ., Israel.* We present a comprehensive FEM-based numerical study of microstructures defined on adiabatic tapered fibers. A practical recipe for the experimental realization of the significant Q-factor values improvement in microknot resonators is demonstrated.

JT5A.21 • Towards Versatile Folded Microfibers: Folded Versus Straight Configuration on Hydrophilic and Hydrophobic Substrates, Alexandra Blank[1], Moti Fridman[2], Yoav Linzon[1]; [1]*Tel Aviv Univ., Israel;* [2]*Bar-Ilan Univ., Israel.* We present durable in-liquid operation with near-infrared light transmitted through fused optical microknot fibers. The persistent detection of transmission resonances in volatile liquids is experimentally demonstrated in various configurations.

JT5A.22 • Processing Technology of Magnetorheological Finishing for Large-aperture Optical Components, Hou Jing[1], Xianhua Chen[1], Jie Li[1], Bo Zhong[1], Wenhui Deng[1]; [1]*China Academy of Engineering Physics, China.* The main parameters of magnetorheological finishing (MRF) affecting removal efficiency were investigated by orthogonal experiment. The large-aperture optical element with high precision was manufactured using the MRF.

JT5A.23 • Fabrication of Optics with a Thin Part by Plasma Chemical Vaporization Machining, Hideo Takino[1]; [1]*Chiba Inst. of Technology, Japan.* Plasma chemical vaporization machining is expected to machine thin wall parts without springback because it produces no force on workpiece surfaces in this study, we fabricate optics with a thin part by the method.

JT5A.24 • Nanofabrication using Transmitted and Diffracted Light Manipulated by Gap Spacing, Taeyeon Kim[1], Heesang Ahn[1], Hyerin Song[1], Jong-Ryul Choi[2], Kyujung Kim[1]; [1]*Pusan National Univ., Korea (the Republic of);* [2]*Dagu-Gyeongbuk Medical Innovation Foundation (DGMIF), Korea (the Republic of).* We designed the experiments to observe the differences between conventional photolithography and plasmonic lithography using the gold hole array by controlling the gap distance between the mask and the photoresist.

JT5A.25 • Implementing Null Phase Screens to Test Fast Singlet Lenses, Maximino Avendaño Alejo[1], Ismael Velázquez-Gómez[1], Adriana Sánchez-Montes[1], Jesús DelOlmo-Márquez[1]; [1]*UNAM ICAT, Mexico.* A new design of null phase screens to test quantitatively fast singlet lenses is presented. The designs of these null screens are based on the knowledge of the propagated wavefront and an exact ray tracing.

JT5A.26 • Numerical Simulation of Axial Misalignment and Tilt of the Spatial Modulator Rays used in the Deflectometry, Diana N. Castán Ricaño[1], Fermín Granados Agustín[1], Andrea Muñoz Potosi[2], Gabriel Valdivieso González[2], María Elizabeth Percino Zacarías[1], Maximino Avendaño Alejo[3], Alejandro Cornejo Rodriguez[1]; [1]*INAOE, Mexico;* [2]*Universidad de Investigación y Desarrollo, Colombia;* [3]*ICAT-UNAM, Mexico.* The numerical results of the simulation performed for a proposed experimental arrangement that measures a reflective spherical surface, we presents results for different errors of displacement and tilt, seen in the detection plane.

JT5A.27 • Application of Interferometry to Control Optical Component with High Accuracy, Aissa Manallah[1]; [1]*Inst. of Optics and Precision Mechanics, Universite Ferhat Abbas Setif 1, Algeria.* Twyman-Green interferometer is used to characterize optical surfaces by quantifying optical surface errors, which appears on the wavefront resulting from interference pattern. Results are accurate, and the technique is convenient and fast.

JT5A.28 • Surface Topography Measurement by Confocal Spectral Interferometry, Aissa Manallah[1]; [1]*Inst. of Optics and Precision Mechanics, Univ. of Setif 1, Algeria.* Confocal spectral interferometry is combination of confocal imaging and spectral interferometry. Confocal system images surface and the interference signal created is analyzed by the spectrometer. The surface topography and roughness are determined.

JT5A.29 • Withdrawn

JT5A.30 • Fabrication of Modified Double Half Wave Band-Pass Filter using Alternately Stacked TiO_2-SiO_2 Multilayer, Mukesh Kumar[1], Neelam Kumari[1], Amit L. Sharma[1], Vinod Karar[1], Ravindra K. Sinha[1]; [1]*CSIR-CSIO, India.* A multilayer band pass filter using 11 layers of alternate TiO_2 - SiO_2 were fabricated on BK7 substrate using ion assisted electron-beam deposition. The fabricated filter offered a bandwidth of 45 nm with a peak transmission of 91.5% at 545 nm.

JT5A.31 • Withdrawn

JT5A.32 • Intracochlear Vibration Measurement using Supercontinuum Multifrequency-swept Optical Coherence Microscope, Samuel Choi[1]; [1]*Niigata Univ., Japan.* Multifrequency swept optical coherence microscope with a supercontinuum was developed for in-vivo intracochlear vibration measurement. 3D-OCT and en-face vibration imaging were successfully conducted with a depth resolution of 2.7 micrometers.

07:00—17:00 • Registration, *Lobby*

Joint Sessions, *P St Combined*

08:00 -- 10:00
JW1A • Freeform Optics Manufacturing I
Presider: Angela Davies; Univ of North Carolina at Charlotte, USA

JW1A.1 • 08:00 Invited
Fabrication, Metrology and Alignment Challenges or Freeform Imaging Systems, Ulrike Fuchs[1]; *[1]Asphericon GmbH, Germany.* Freeform surfaces enable numerous new applications. However, they imply new challenges as well. The higher number of degrees of freedom necessarily require a constant traceability of all references during manufacturing and for system assembly.

JW1A.2 • 08:30
Design and Manufacturing Considerations for Freeform Optical Surfaces, Steve Powers[1], Matt Brunelle[1], Matt Novak[2]; *[1]Optimax Systems Inc, USA; [2]Synopsys, Inc., USA.* Freeform optical systems are becoming more common due to new design and manufacturing methods. We present an example compact freeform optical system and describe considerations for transfer of the prescription of freeform surfaces for fabrication.

JW1A.3 • 08:45
Importance of Accurate Datums in Freeform Manufacturing, Franciscus L. Wolfs[1], Scott Defisher[1]; *[1]OptiPro Systems, USA.* A study on the importance of using accurate datums is presented through an analysis on the sensitivity of surface form and figure to the quality of datum surfaces.

JW1A.4 • 09:00
Precision Glass Molding of Freeform Optics, Dustin K. Gurganus[1], Alan Symmons[2], Matt Davies[1], Spencer Novak[2]; *[1]Univ. of North Carolina at Charlotte, USA; [2]LightPath Technologies, USA.* Precision glass molding is an enabling high-volume optical manufacturing method. Through optical design, mold tooling design, manufacture, and precision glass molding, a 45 mm freeform Alverez lens was generated to meet certain specifications.

JW1A.5 • 09:15
Manufacturing High-Gradient Freeform Continuous Phase Plates (CPPs) using Magnetorheological Finishing, Joseph A. Menapace[1], Aaron S. Peer[1], Gary Tham[1]; *[1]Lawrence Livermore National Laboratory, USA.* Advanced MRF technology can be used to fabricate CPPs with high topographical gradients through careful selection of MRF parameters and removal functions. Appropriate evaluation criteria also provide vital information to determine completion.

JW1A.6 • 09:30 Invited
Fabrication and Measurement of Large Scale Freeform Optics, Dae Wook Kim[1], Isaac Trumper[1], Logan Graves[1], Maham Aftab[2], Heejoo Choi[1], Brian Kellermeyer[1], Lei Huang[3], Andrew Lowman[1], Chang Jin Oh[1]; *[1]Univ. of Arizona, USA; [2]ASML, USA; [3]Tsinghua Univ., China.* Utilizing freeform optics in an optical system improves the system's overall performance and form-factor. These benefits come at a cost, both financial and technical, as freeform optics require advanced design, fabrication, and testing methods.

10:00—10:30 • Networking Coffee Break, *Perkin and Small Conference Rooms*

10:30 -- 12:30
JW2A • Freeform Optics Metrology and Testing
Presider: Jannick Rolland; Univ. of Rochester, USA

JW2A.1 • 10:30 Invited
Aligning Freeform Systems with Deflectometry, Angela D. Davies[1], Trent Vann[1], Chris J. Evans[1], Mark Butkiewicz[2]; *[1]Univ of North Carolina at Charlotte, USA; [2]Survice Engineering, USA.* Freeform alignment is critical and challenging, often relying on mechanical fixturing. We discuss an optical approach based on deflectometry. A pattern on a screen is imaged through the freeform under investigation and the distortion in the pattern is a combination of the freeform surface shape and the alignment condition. The misalignment is evaluated using a Zernike analysis of the image distortion, knowledge of the surface shape, and an empirically-determined misalignment dependence. The approach is investigated through simulation in the context of segment misalignment in a segmented mirror, showing that 5 degrees of freedom of misalignment can be determined with micrometer-scale and micro radian-scale sensitivities.

JW2A.2 • 11:00
Absolute Freeform Surface Measurement using Interferometry, Greg Frisch[1], Thomas Hordin[1]; *[1]Optimax Systems Inc, USA.* We will present a case study of a characteristic freeform production optic that required an absolute positioning measurement procedure utilizing a custom dual computer generated hologram (CGH) interferogram set-up.

JW2A.3 • 11:15
Independent In-process Figure Convergence Metrology for Freeform Optics, Nicholas W. Horvath[1], Todd Noste[1], Matt Davies[1], Chris J. Evans[1]; *[1]Univ of North Carolina at Charlotte, USA.* Deterministic in-process metrology is prerequisite for sub-micrometer figure accuracy. Independent metrology is required to correct systematic error motions in the manufacturing. Final acceptance requires independent validations of the manufacturing.

JW2A.4 • 11:30
Metrology Techniques for Ultra-precision Diamond Turned Freeform Optics, Daliramu Burada[1], Kamal K. Pant[1], Vinod Mishra[1], Ashish Dwivedi[1], Lalit Pant[1], Gufran Khan[1], Chandra Shakher[1]; *[1]Indian Inst. of Technology Delhi, India.* The paper presents a comparative study of different metrology techniques for the measurement of ultra-precision diamond turned freeform optics. Their limitations and advantages are being discussed and compared. The experimental results are presented.

JW2A.5 • 11:45
Null-screen Design for Freeform Surface Testing, Daniel Aguirre[1], Brenda Villalobos-Mendoza[2], Rufino Díaz-Uribe[1], Manuel Campos-García[1]; *[1]ICAT-UNAM, Mexico; [2]Física y Matemáticas, UDEM, Mexico.* We present the null-screen design for testing the shape of freeform surfaces. To validate the proposed method, we calculated the null-screen for the Zernike surface (n=3, m=-3), with a peak to valley (PV) of 31.765 mm.

JW2A.6 • 12:00
Design of a Flexible On-axis Interferometric Null Test for Off-axis Parabolic and Toroidal Mirrors, Romita Chaudhuri[1], Jannick P. Rolland[1]; *[1]Univ. of Rochester, USA.* A simulated flexible null test with a high-definition spatial light modulator (SLM) as a reconfigurable nulling element is reported. On-axis testing and the ability to display fiducials on the SLM decouples misalignment and form errors.

JW2A.7 • 12:15
Development of a Convex Surface Measurement Using Prescription Retrieval, Aaron Michalko[1], James R. Fienup[1]; *[1]Univ. of Rochester, USA.* The test geometry for a subaperture-scanning measurement technique for convex optical surfaces is discussed. Preliminary simulations of a convex spherical measurement using a prescription retrieval algorithm are demonstrated.

12:30—14:00 • *Hosted Lunch*

Joint Session, *P St Combined*

14:00 -- 16:00
JW3A • Freeform Optics Manufacturing II
Presider: Ulrike Fuchs; Asphericon GmbH, Germany

JW3A.1 • 14:00 Invited
Precision Glass Molding of Freeform Optics, Jeremy Huddleston[1], Spencer Novak[1], Lou Mertus[1], Alan Symmons[1]; *[1]LightPath Technologies, USA.* Precision glass molding (PGM), is a mature technology that can uniquely address both the technical challenges and the high-volume scalability of manufacturing freeform optics. The authors review the requirements for successful implementation of PGM freeforms.

JW3A.2 • 14:30
Design-for-manufacture of High-resolution 3D Printed Rotation Optics, Ingo Sieber[1], Daniel Moser[1], Ulrich Gengenbach[1]; *[1]Inst. for Automation and Applied Informatics, Karlsruhe Inst. of Technology, Germany.* Design and manufacture of a novel varifocal freeform optics by means of high-resolution 3D printing are presented. Tuning of its focal length is achieved by mutually rotating two lens bodies around the optical axis.

JW3A.3 • 14:45
Evaluation of a 3D Printed Freeform Reflector and Lens, Andre Sigel[1], Mike Dohmen[1], Andreas Heinrich[1]; *[1]Center for Optical Technologies, Aalen Univ., Germany.* A lens and a freeform reflector designed for a metrology setup are presented. The optical design approaches as well as an evaluation of the 3D printed optical components are provided.

JW3A.4 • 15:00
Pushing Freeform Optical Manufacturing: Fabricating Optimax's Largest Freeform Component, Matt Brunelle[1], Ian Ferralli[1], Jennifer Coniglio[1], Timothy Lynch[1], Todd Blalock[1], Jessica DeGroote Nelson[1]; *[1]Optimax Systems Inc., USA.* Several challenges associated with part size and shape complexity were solved during the manufacture of the largest extreme freeform shape Optimax has fabricated to date. These challenges and their solutions will be discussed.

JW3A.5 • 15:15
Replication of a Polymer Surface Plasmon Resonance Freeform Optical Element, Michael Vervaeke[1], Jurgen Van Erps[1], Jens De Pelsmaeker[1], Heidi Ottevaere[1], Hugo Thienpont[1]; *[1]Department of Applied Physics and Photonics, Brussels Photonics (B-PHOT), Vrije Universiteit Brussel and Flanders Make, Belgium.* Surface Plasmon Resonance devices have the promise to become the prevailing device technology for miniaturized point-of-care diagnosis. We have designed, fabricated and tested a disposable freeform SPR device outperforming traditional prism devices.

JW3A.6 • 15:30
Slanted Fast Tool Enables Efficient Freeform Machining for Infrared Applications, Dan Gauch[1], Frank Niehaus[2], Frank Niehaus[2]; *[1]Schneider Optical Machines, USA; [2]Schneider GmbH & Co, Germany.* Slanted Fast Tool design with twin tool enables efficient infrared freeform cutting strategies that are cost effective, automate tool change and height adjustment, and provide a rigid mechanical system that yields very high form accuracy.

JW3A.7 • 15:45
Quadratic Extension to Retrace Error Calibration Algorithm for Non-null Interferometric Surface Figure Testing of Nominally Flat Reflective Surfaces, Martin Tangari Larrategui[1,2], Yanqi Zhang[2], Andrew D. Rocha[2], Thomas G. Brown[1], Jonathan D. Ellis[2]; *[1]Univ. of Rochester, USA; [2]Univ. of Arizona, USA.* We present a slope dependent calibration algorithm for interferometric surface figure testing. RMS wavefront error is reduced 40.7% (10.8% for linear method) from the uncalibrated measurement for a R/22.7 mirror tested against a flat reference.

16:00—16:30 • Networking Coffee Break, *Perkin and Small Conference Rooms*

P St A	P St B
OF&T	**Freeform**

16:30 -- 18:30
OW4A • Optical Metrology and Testing
Presider: Paul Dewa; Corning Tropel Corporation, USA

OW4A.1 • 16:30 Invited
Analyzing and Minimizing Mid-spatial Frequency Errors, Sven R. Kiontke[1], Ulrike Fuchs[1]; [1]*Asphericon GmbH, Germany.* This paper is dealing with different specifications and tolerancing of Mid-spatial frequency (MSF) for aspheric and freeform surfaces. Various models are discussed with respect to suitability for optical design, manufacturing, and metrology.

OW4A.2 • 17:00
Fitting Surface Metrology Data: Is it Alignment, Radius, or Irregularity Error?, Paul E. Murphy[1], Chris Supranowitz[1], Jacob Siegel[1]; [1]*QED Technologies Inc, USA.* Optical surface measurements include alignment error from rigid body position uncertainty. Extracting irregularity from the measurement is straightforward for spheres. We examine challenges when fitting alignment error on aspheres and freeforms.

OW4A.3 • 17:15
Alignment Errors vs. Measurability for Null-measurements of Aspheres, Felix Lucas[1], Roland Schreiner[1], Thomas Waak[1], Kai Gäbel[1], Lutz Reichmann[1]; [1]*Jenoptik Optical Systems GmbH, Germany.* We show that an imperfectly aligned asphere-CGH-measurement leads to artifacts that are indistinguishable from common manufacturing errors such as trefoil and spherical aberration. We apply a machine learning approach to correct for these artifacts.

OW4A.4 • 17:30 Invited
Active Optics for Space Telescopes, Nicholas Devaney[1]; [1]*School of Physics, National Univ. of Ireland Galway, Ireland.* This paper provides a historical review of Active Optics, with emphasis on the application to Space Telescopes. It will conclude with results of a laboratory prototype system.

OW4A.5 • 18:00
Improved FRFT-based Method for Estimating Physical Parameters from Newton's Rings, Zhen Guo[1,2], Ming-Feng Lu[1,2], Jin-Min Wu[1,2], Feng Zhang[1,2], Ran Tao[1,2]; [1]*School of Information and Electronics, Beijing Inst. of Technology, China;* [2]*Beijing Key Laboratory of Fractional Signals and Systems, China.* An improved FRFT-based method for estimating parameters from Newton's rings is proposed that can estimate parameters in about 1.3 seconds when processing a 1920 × 1080 pixel image of Newton's rings.

OW4A.6 • 18:15
Super Sensitive Deflectometry Beyond the MTF Limit, Luke DeMars[1], Ana Ramirez-Andrade[1], Rosario G. Porras Aguilar[1], Konstantinos Falaggis[1]; [1]*UNC Charlotte, USA.* A super-sensitive phase measuring deflectometry technique is presented to obtain effective fringe periods beyond the MTF limit. This allows decreasing significantly the random component of the uncertainty in the measured slope.

16:30 -- 18:15
FW4B • Freeform Systems
Presider: Dae Wook Kim; Univ. of Arizona, USA

FW4B.1 • 16:30
The Validity of the Perturbation Model for the Propagation of MSF Structures, Kevin Liang[1,2], Greg W. Forbes[3,2], Miguel A. Alonso[1,2]; [1]*Inst. of Optics, USA;* [2]*Center for Freeform Optics, USA;* [3]*Physics and Astronomy, Macquarie Univ., Australia.* The perturbation model is often employed when assessing performance degradation caused by mid-spatial frequency (MSF) structures. However, the model's validity is poorly understood. We present a rule of thumb regarding this validity.

FW4B.3 • 17:00
Exact Ray Tracing through Freeform Lenses, Jesús DelOlmo-Márquez[1], Gabriel Castillo-Santiago[1], Maximino Avendaño-Alejo[1]; [1]*ICAT-UNAM, Mexico.* We have considered an exact ray tracing through freeform lenses by using vectorial Snell's law, assuming a bundle of incident rays propagating along the Z-axis. A preliminary test for Zernike's lenses has been properly implemented .

FW4B.2 • 16:45
Design of Freeform Phase Plate Pairs for Variable Extended Depth of Field in Imaging Systems, Sara Moein[1], Thomas J. Suleski[1]; [1]*Univ of North Carolina at Charlotte, USA.* Increasing depth of field is highly beneficial, particularly for high NA imaging systems. We discuss approaches to enable variable, extended depth of field through relative movements between pairs of freeform surfaces.

FW4B.4 • 17:15
A Simplified System Integration Approach for Brittle Material Freeform Optics, Matthias Beier[1], Burak Çibuk[1], Johannes Hartung[1], Andreas Gebhardt[1], Stefan Risse[1]; [1]*Fraunhofer IOF, Germany.* A novel design approach for a simplified integration of complex shaped mirrors made out of a brittle material is presented. It is based on a sub-sequent ultra-precise machining of optical and mechanical interfaces assembled to the brittle substrate.

FW4B.5 • 17:30
The Potential of Freeform Micro-optical Elements on Light Management Foils, Claude Leiner[1], Wolfgang Nemitz[1], Ladislav Kuna[1], Werner Faerber[2], Christian Sommer[1]; [1]*Joanneum Research Forschungsges. GmbH, Austria;* [2]*EcoCan GmbH, Austria.* FF-micro-optical elements on foil are showing a great potential because of combining the unique ability of freeform optical surfaces of achieving desired radiant intensity or irradiance distributions with the compactness of light management foils.

FW4B.6 • 17:45 Invited
Building Challenging Optical Systems with Alvarez Lenses, Eckhard E. Roth[1], Hannes Scheibe[1], Thomas Koehler[1], Schindler Christian[1]; [1]*Development Optical Systems, Carl Zeiss Jena GmbH, Germany.* Alvarez-FF are known to be used for universal wave front manipulation and thus become more popular. Their usage in optical systems induces many challenges from manufacturing, tolerancing, mounting, aligning and measuring them and the optical system.

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